MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2016/2017

EME4016 – HEAT TRANSFER

(ME)

1 MARCH 2017
9.00 a.m - 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of seven pages including the cover page and appendices.

2. Answer ALL four questions. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].

3. Write all your answers in the Answer Booklet provided.

Question 1

A cylindrical bar of a semiconductor material with thermal conductivity 1.2 $W/m\cdot℃$ has a cross-sectional area of 1 cm^2 and a length of 3 cm. The left end is maintained at 300 ℃ and the right end is at 100 ℃. The bar carries an electrical current which gives rise to a heat generation of 5.4 MW/m^3. Assume the circumferential surface of the bar to be perfectly insulated. You may also assume that the conduction is only in one direction, along the bar (one-dimension), and that it is in steady state.

(a) Draw a diagramme and write down the appropriate conduction equation and the necessary boundary conditions, taking the origin at the middle of the centerline of the bar.

[4 marks]

(b) Solve the equation in part (a) and calculate the mid-point temperature in the bar.

[12 marks]

(c) If the circumference of the bar is not insulated but subjected to a convective coefficient of h, write down the equation and boundary conditions for this new steady state two-dimensional problem. Take the origin in the same position as in part (b). Do not solve the equation.

[5 marks]

(d) In part (c), if initially the whole rod is at 0 ℃, write down the appropriate conduction equation and the boundary conditions for the unsteady two-dimensional problem. Do not solve the equation.

[4 marks]

Note: One general form of the conduction equation is

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \nabla^2 T + \dot{q}/k,$$

with $T(\vec{r}, t)$, and other symbols have their usual meanings.

In cylindrical coordinates, $\nabla^2 T = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{\partial^2 T}{\partial z^2}$.

Continued...

Question 2

A special purpose oven is modelled as a long duct with an equilateral triangle cross section. Consider radiation exchanges among three surfaces 1, 2 and 3, representing the two walls and the base of the duct, respectively. Surface 1 has temperature 1100 K and emissivity 0.6. Surface 2 has temperature 2100 K and emissivity 0.8. Surface 3 is the horizontal base and has emissivity 0.7 but its temperature is unknown. However it is known that surface 3 has a heat flux of 1000 W/m^2. You may assume that each surface area is 1 m^2.

(a) Draw the thermal circuit for this three-body problem, labelling all nodes and resistances with a consistent notation.

[6 marks]

(b) Find the numerical values of all the resistances that you have labelled in part (a).

[6 marks]

(c) Find the heat flux at surface 2.

[10 marks]

(d) Find the temperature of surface 3.

[3 marks]

Take the Stefan-Boltzmann constant to be $5.67 \times 10^{-8}\, W/m^2 \cdot K^4$.

Question 3

(a) A certain fluid enters a circular tube, of length $L = 60.0$ m and inner diameter $d = 2.5$ cm, with a mean axial velocity of 0.60 m/s and a bulk temperature of 15.0 °C. It leaves the tube with the same mean velocity but with a bulk temperature of 115.0 °C. The inner wall of the tube is maintained at a uniform temperature of 120.0 °C.

(i) Calculate the mass flow rate, in units of kg/s, of the fluid inside the tube.

[3 marks]

Continued...

(ii) Calculate the rate of heat transfer, in units of kW, from the tube to the fluid.

[3 marks]

(iii) Calculate the average heat transfer coefficient $\bar{h}_L$ for the entire tube length.

[9 marks]

You may assume that the density, specific heat, and thermal conductivity of the fluid are constant and given by $\rho = 980.4$ kg/m^3, $c_p = 4.187$ kJ/kg·K, and $k = 0.659$ W/m·K, respectively.

(b) A rectangular plate, of length $L = 0.50$ m and width $w = 0.25$ m, is placed in a uniform stream of a fluid at $T_\infty = 50$ °C. The plate is oriented in such a way that the two sides of length L are parallel to the free-stream velocity $U = 0.30$ m/s. The plate is maintained at a uniform temperature of T_w ($T_w > T_\infty$) by an embedded electric heater. The heat transfer from one side of the plate to the fluid stream is given by the local Nusselt number

$$\mathrm{Nu}_x = 0.332\ \mathrm{Pr}^{1/3}\ \mathrm{Re}_x^{1/2}$$

where Pr is the Prandtl number, Re_x is the local Reynolds number, and the coordinate x denotes the distance from the leading edge of the plate. (Note that the length scale for Nu_x and Re_x is the coordinate x.)

(i) By averaging the local heat transfer coefficient h_x over the plate length L, determine the average heat transfer coefficient $\bar{h}_L$ in terms of Pr and Re_L.

[4 marks]

(ii) Determine the power which must be supplied by the electric heater to the plate in order to maintain T_w at 100 °C. For this purpose, assume the following property values for the fluid: kinematic viscosity $\nu = 3.88 \times 10^{-7}$ m^2/s, thermal diffusivity $\alpha = 1.63 \times 10^{-7}$ m^2/s, and thermal conductivity $k = 0.667$ W/m·K.

[6 marks]

Continued...

Question 4

(a) A plane wall with surface temperature of 300 °C is attached with straight aluminium triangular fins (k = 236 W/m·K) as shown in **Fig Q4(a).** The fins are exposed to ambient air condition of 25 °C and the convection heat transfer coefficient is 25 W/m^2·K. Each fin has a length of 55 mm, a base of 4 mm thick and a width of 110 mm. Determine the following for each fin.

(i) Efficiency. **[4 marks]**

(ii) Heat transfer rate. **[4 marks]**

(iii) Effectiveness of each fin. **[5 marks]**

Note: The modified Bessel functions in this case are given by: $I_0(2mL) = 1.166$ and $I_1(2mL) = 0.4329$. Refer to Appendix A.

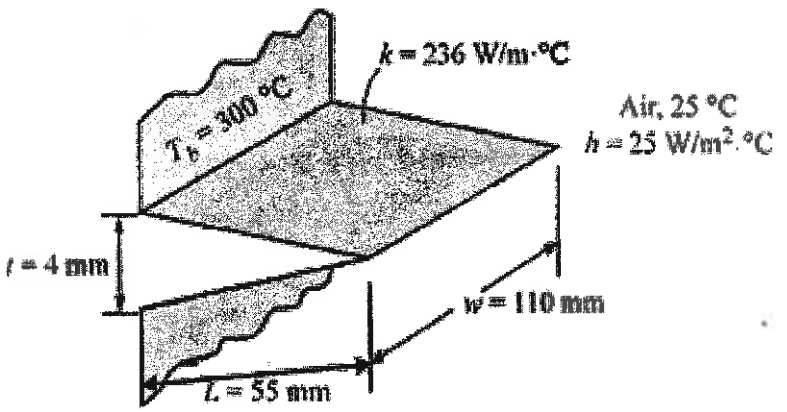

Fig Q4(a)

Continued...

(b) Oil in an engine is being cooled by air in a cross-flow heat exchanger, where both fluids are unmixed. Oil (c_{ph} = 2047 J/kg·K) flowing with a flow rate of 0.026 kg/s enters the heat exchanger at 75 °C, while air (c_{pc} = 1007 J/kg·K) enters at 30 °C with a flow rate of 0.21 kg/s as shown in **FigQ4 (b).** The overall heat transfer coefficient of the heat exchanger is 53 W/m^2.K and the total surface area is 1 m^2. Determine:

(i) The heat transfer effectiveness. **[6 marks]**

(ii) The outlet temperature of the oil. **[6 marks]**

Refer to Appendix B.

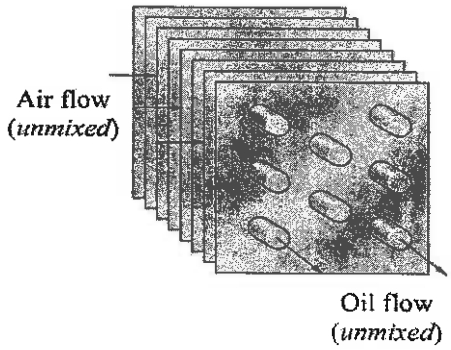

Fig Q4(b)

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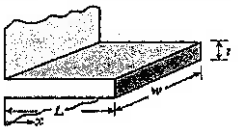
Appendix A: Efficiency of common fin configurations

Straight rectangular fins

$m = \sqrt{2h/kt}$
$L_c = L + t/2$
$A_{fin} = 2wL_c$

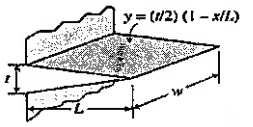
$$\eta_{fin} = \frac{\tanh mL_c}{mL_c}$$



Straight triangular fins

$m = \sqrt{2h/kt}$
$A_{fin} = 2w\sqrt{L^2 + (t/2)^2}$

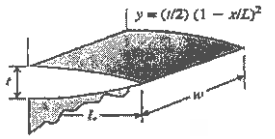
$$\eta_{fin} = \frac{1}{mL}\frac{I_1(2mL)}{I_0(2mL)}$$



Straight parabolic fins

$m = \sqrt{2h/kt}$
$A_{fin} = wL[C_1 + (L/t)\ln(t/L + C_1)]$
$C_1 = \sqrt{1 + (t/L)^2}$

$$\eta_{fin} = \frac{2}{1 + \sqrt{(2mL)^2 + 1}}$$

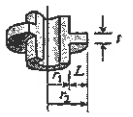


Circular fins of rectangular profile

$m = \sqrt{2h/kt}$
$r_{2c} = r_2 + t/2$
$A_{fin} = 2\pi(r_{2c}^2 - r_1^2)$

$$\eta_{fin} = C_2\frac{K_1(mr_1)I_1(mr_{2c}) - I_1(mr_1)K_1(mr_{2c})}{I_0(mr_1)K_1(mr_{2c}) + K_0(mr_1)I_1(mr_{2c})}$$

$$C_2 = \frac{2r_1/m}{r_{2c}^2 - r_1^2}$$



Appendix B: NTU relations for heat exchangers

Effectiveness relations for heat exchangers: NTU = UA_s/C_{min} and $c = C_{min}/C_{max} = (\dot{m}c_p)_{min}/(\dot{m}c_p)_{max}$

Heat exchanger type	Effectiveness relation
1 *Double pipe:*	
Parallel-flow	$\varepsilon = \dfrac{1 - \exp[-\text{NTU}(1 + c)]}{1 + c}$
Counter-flow	$\varepsilon = \dfrac{1 - \exp[-\text{NTU}(1 - c)]}{1 - c\exp[-\text{NTU}(1 - c)]}$
2 *Shell-and-tube:* One-shell pass 2, 4,...tube passes	$\varepsilon = 2\left\{1 + c + \sqrt{1 + c^2}\,\dfrac{1 + \exp[-\text{NTU}\sqrt{1 + c^2}]}{1 - \exp[-\text{NTU}\sqrt{1 + c^2}]}\right\}^{-1}$
3 *Cross-flow (single-pass)* Both fluids unmixed	$\varepsilon = 1 - \exp\left\{\dfrac{\text{NTU}^{0.22}}{c}[\exp(-c\ \text{NTU}^{0.78}) - 1]\right\}$
C_{max} mixed, C_{min} unmixed	$\varepsilon = \dfrac{1}{c}(1 - \exp\{-c[1 - \exp(-\text{NTU})]\})$
C_{min} mixed, C_{max} unmixed	$\varepsilon = 1 - \exp\left\{-\dfrac{1}{c}[1 - \exp(-c\ \text{NTU})]\right\}$
4 *All heat exchangers with* $c = 0$	$\varepsilon = 1 - \exp(-\text{NTU})$

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End of Paper